

Feedbacks: Oceans and El Niño

EES 3310/5310

Global Climate Change

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Class #9: Monday, January 27 2020

Kombayashi-Ingersoll Limit

- Outgoing long-wave has to balance incoming sunlight
- **no feedback**, **feedback**, feedback + high CO₂
- Brighter sun → hotter → more water vapor
- Kombayashi-Ingersoll limit:
 - Sunlight below limit, there is a stable equilibrium with liquid water
 - Sunlight above limit:
 - Runaway greenhouse effect
 - Oceans boil dry
- Earth is well below the limit
- Venus is well above the limit
 - Rain and surface-water is important for removing CO₂ from atmosphere
 - Without liquid water Venus's CO₂ went out of control
 - 220,000 times more CO₂ than Earth's atmosphere

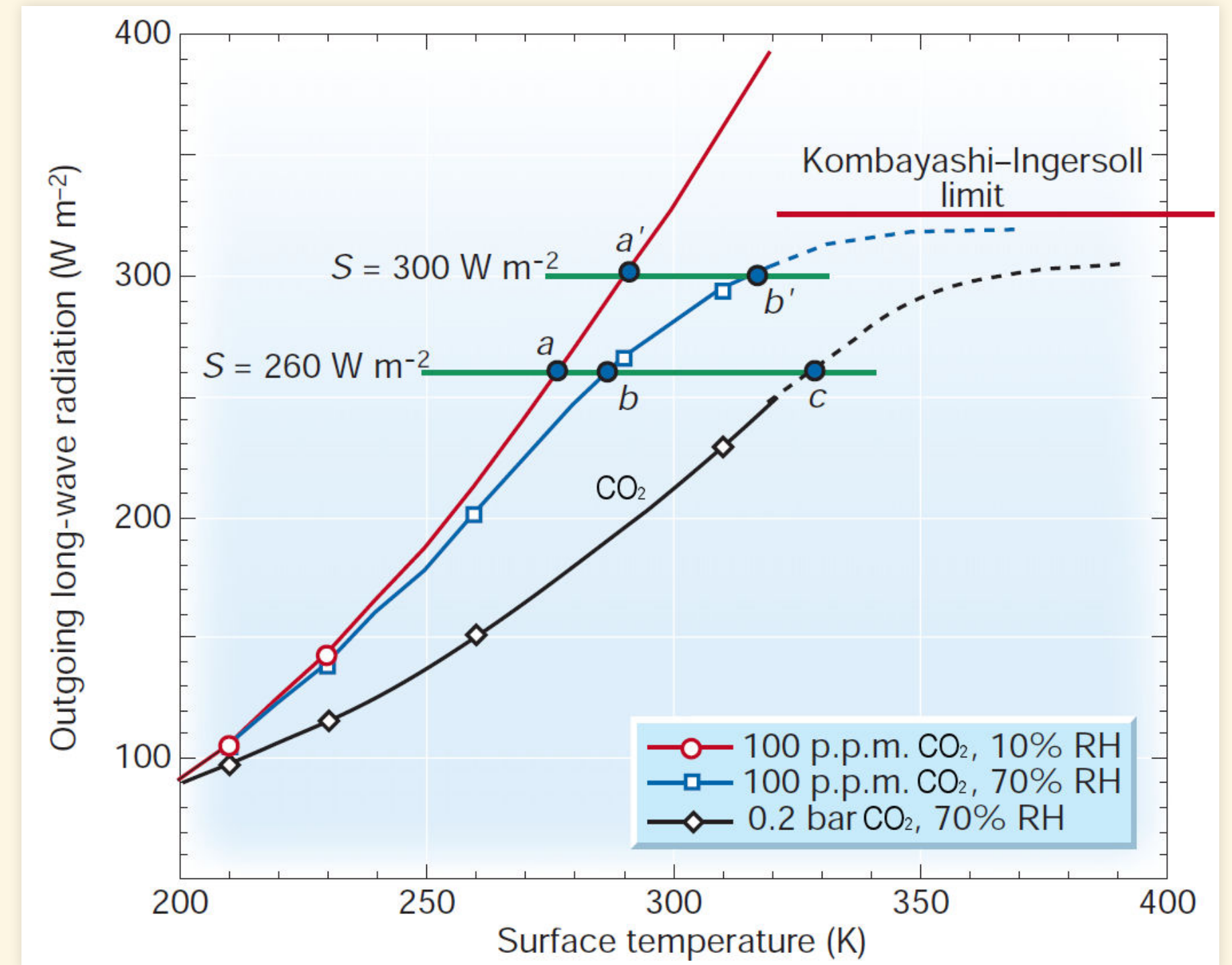


Image credit: R. Pierrehumbert, Nature 419, 191 (2002) doi: [10.1038/nature01088](https://doi.org/10.1038/nature01088)

Cloud Feedbacks



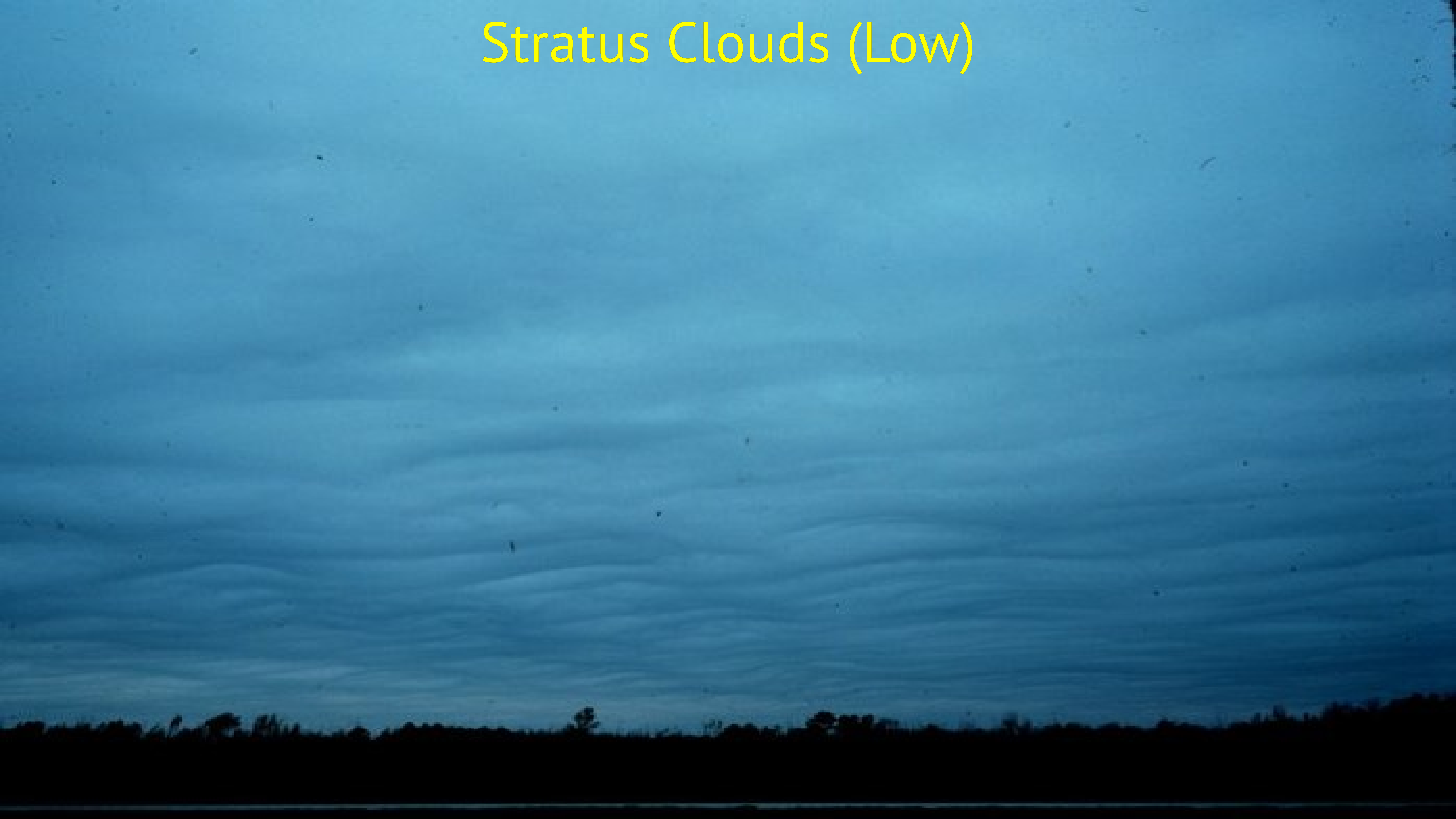
Cloud Feedbacks

- What effect do clouds have on climate?
- What effects does climate have on clouds?
- Warmer → more clouds
- More clouds:
 - Higher albedo
 - (cools earth: negative feedback)
 - High emissivity: blocks longwave light
 - (warms earth: positive feedback)
- Which effect is bigger?

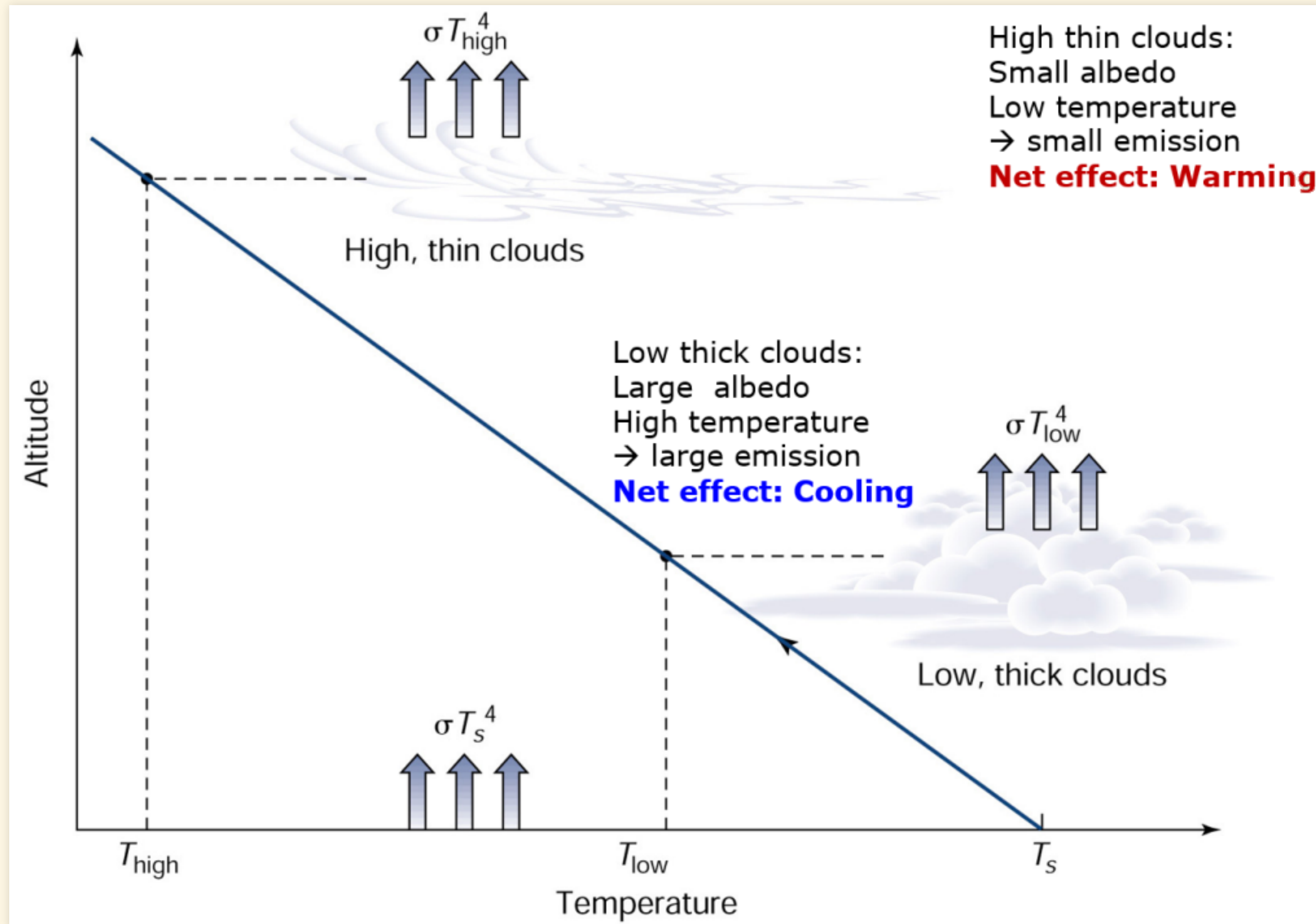
Cirrus Clouds (High)



Stratus Clouds (Low)



Cloud Feedbacks



Satellite Measurements

Radiative forcing by clouds

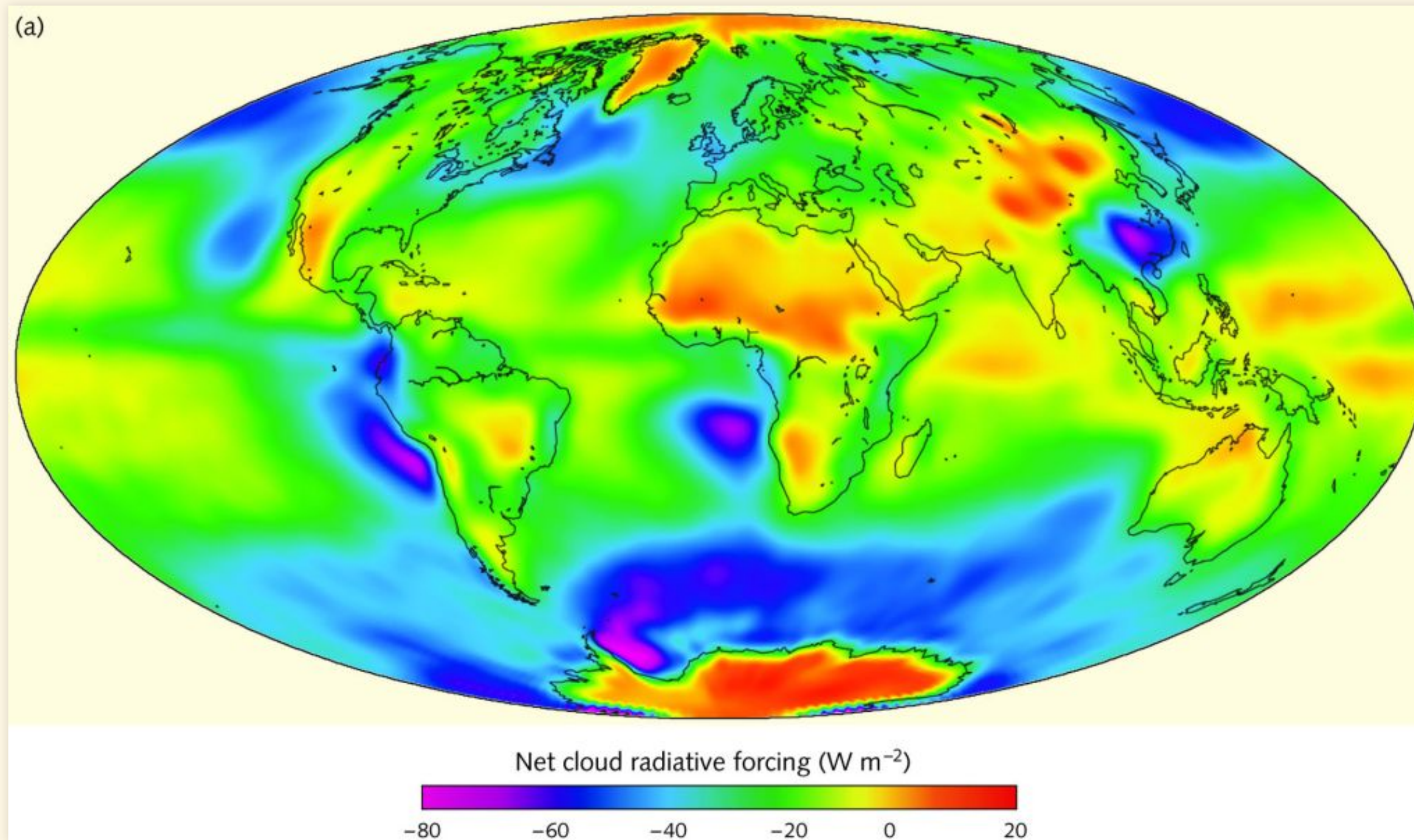


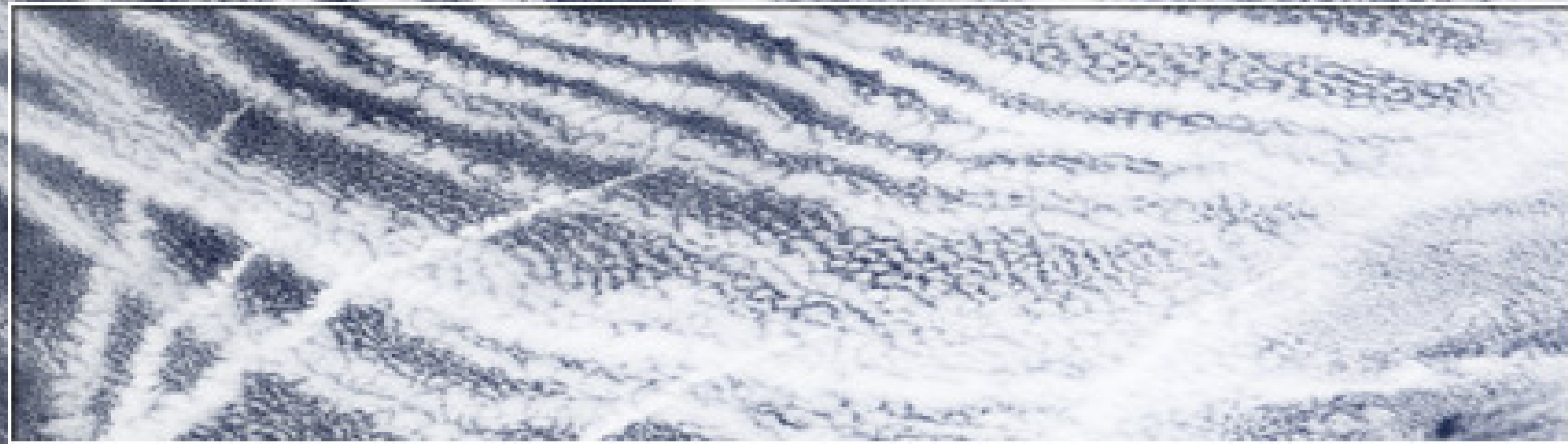
Image credit: NASA CERES/Terra experiment, Net Cloud Radiative Forcing, Nov. 2007 https://ceres.larc.nasa.gov/documents/press_releases/images/netcrf_small.png

(negative = cooling, positive = warming)

Indirect Aerosol Effect

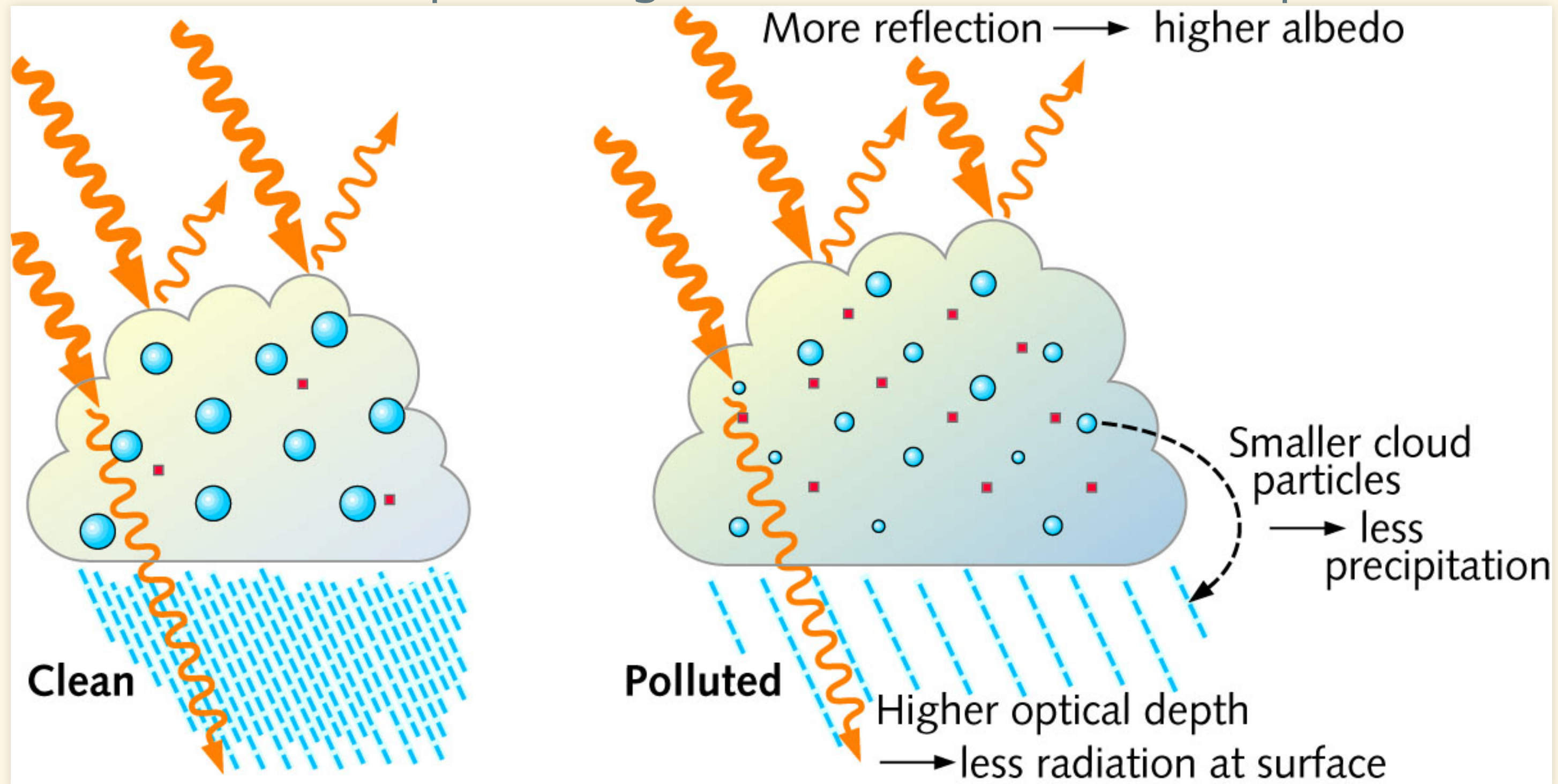
—ship track

marine layer



Indirect Aerosol Effect

- Aerosol particles → more, smaller droplets
- Smaller droplets → greater albedo, longer lifetime
- More droplets → greater albedo, more absorption



Indirect Aerosol Effect

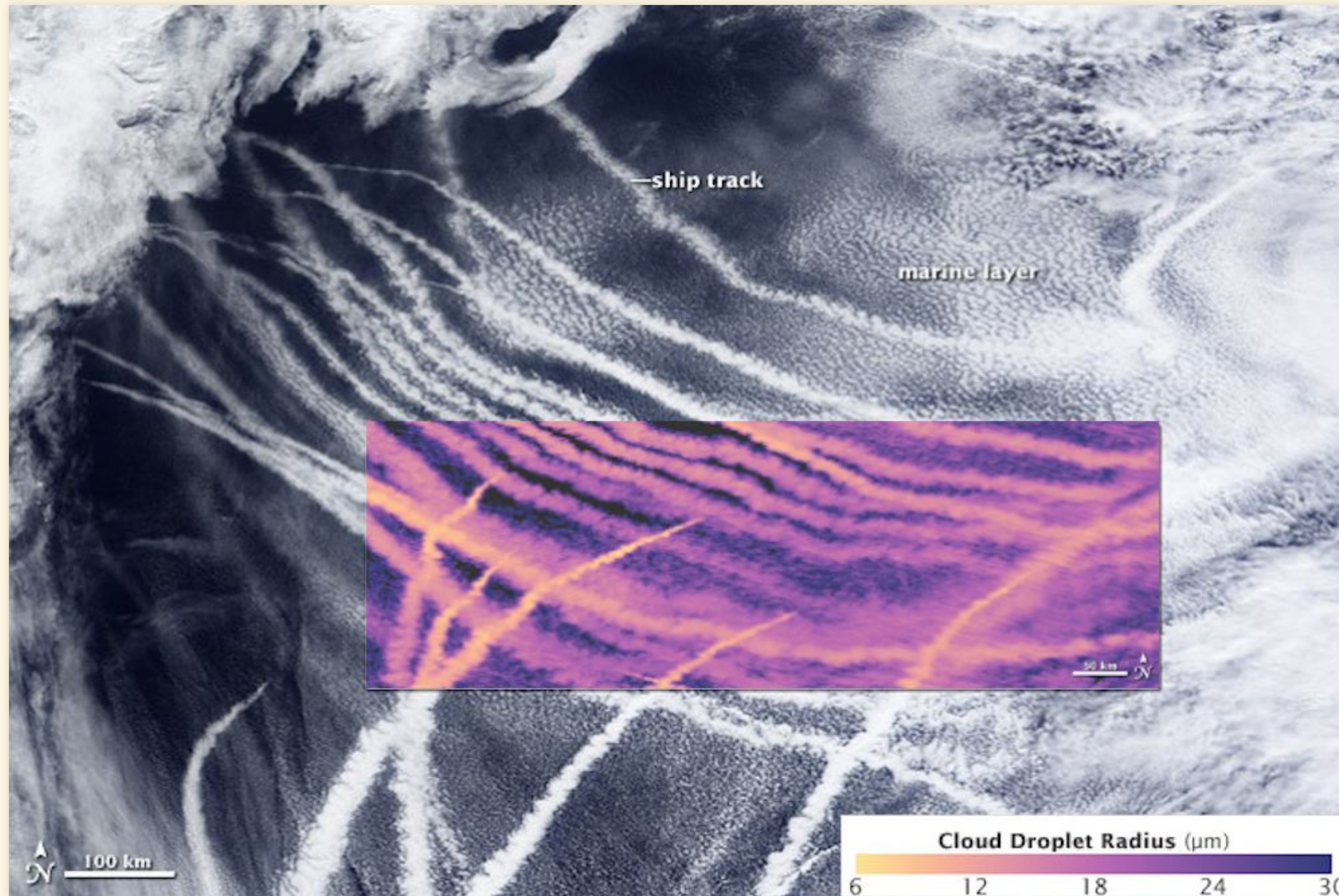
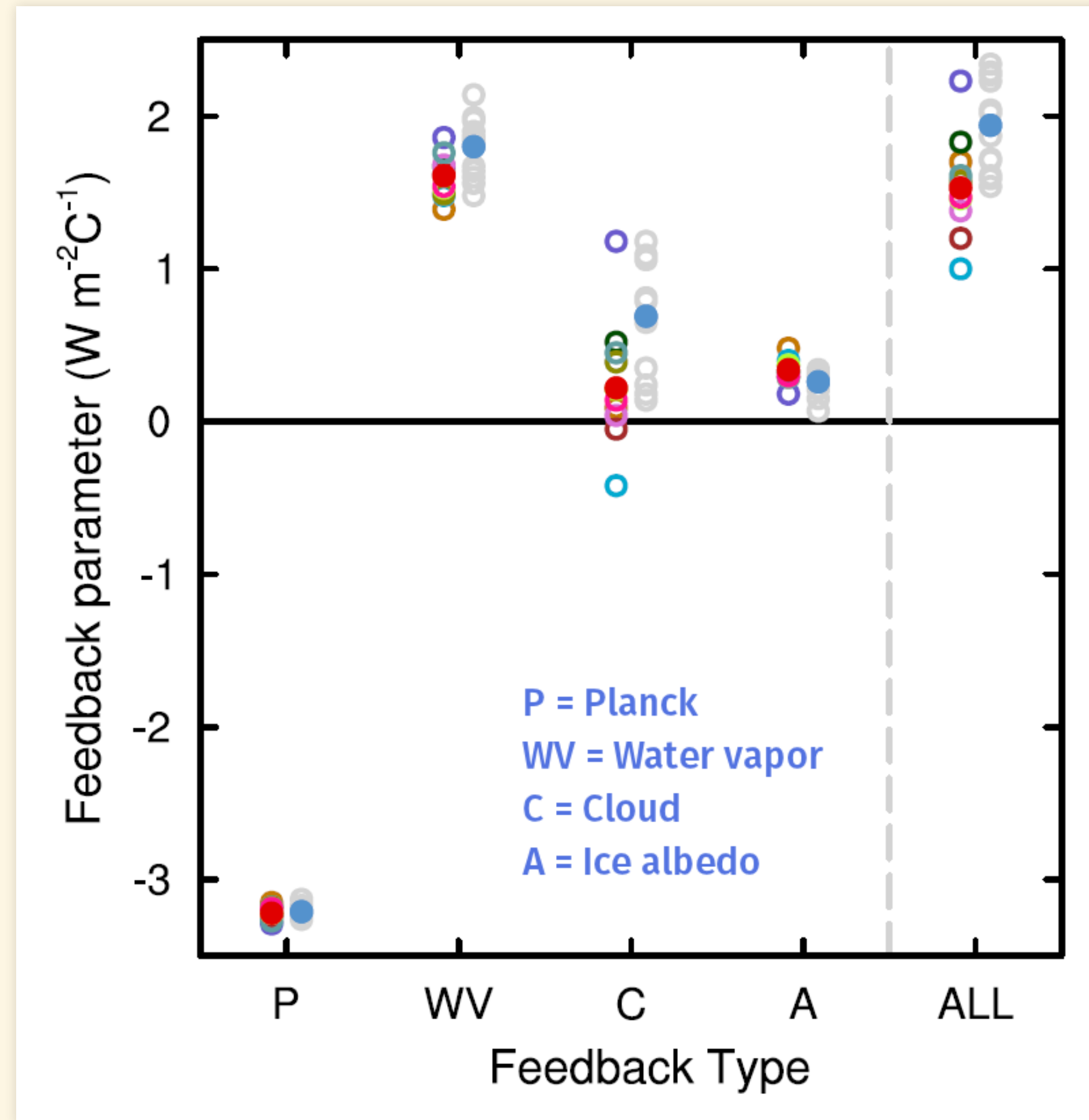


Image credit: NASA Earth Observatory, Ship Tracks South of Alaska, Mar. 4 2009. <https://earthobservatory.nasa.gov/images/37455/ship-tracks-south-of-alaska>

Summary of Feedbacks

Summary of Feedbacks



Stefan-Boltzmann Feedback

- The biggest feedback in the climate system is the Stefan-Boltzmann feedback.
- Stefan-Boltzmann equation: $I = \varepsilon \sigma T^4$
 - $Q = Q_{\text{in}} - Q_{\text{out}}$
 - Higher temperature \rightarrow more heat out to space
 - Q_{out} gets larger, so $\Delta Q < 0$
 - $\Delta T > 0 \rightarrow \Delta Q < 0$
 - $f = \frac{\Delta Q}{\Delta T} < 0$: negative feedback
- Creates stable climate

Stefan-Boltzmann Feedback

Bare rock:

- $I_{\text{out}} = \epsilon \sigma T^4$
- $f_{\text{SB}} = -3.2 \text{ Wm}^{-2} \text{K}^{-1}$
- Forcing: $Q_{\text{forcing}} = I_{\text{in}} - I_{\text{out}} = +1 \text{ Wm}^{-2}$
- $\Delta T = -Q_{\text{forcing}} / f$

$$\Delta T = \frac{-1 \text{ Wm}^{-2}}{-3.2 \text{ Wm}^{-2} \text{K}^{-1}} = +0.32 \text{ K}$$

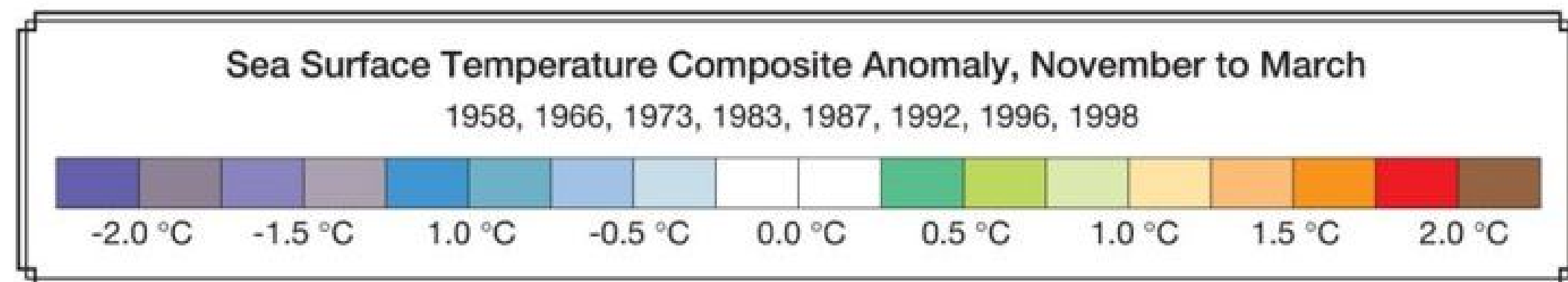
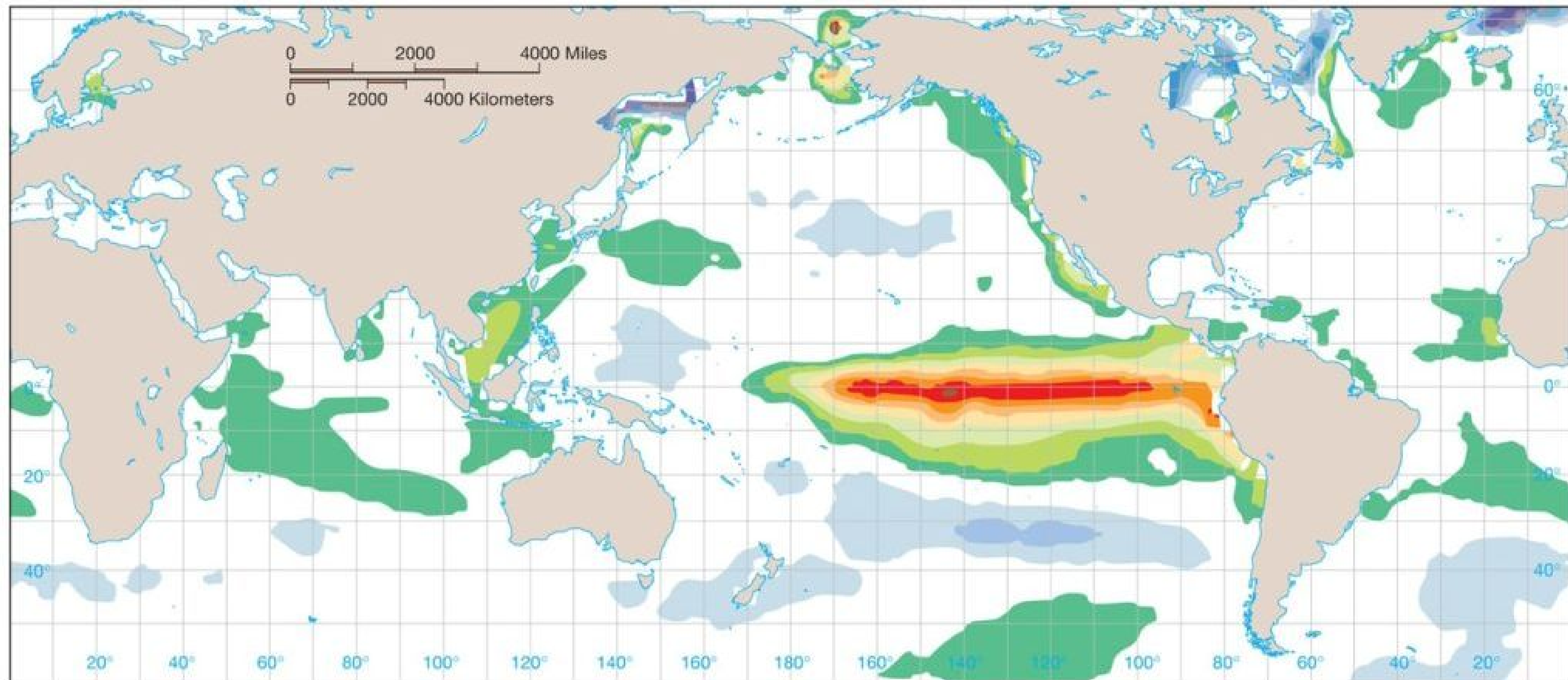
Positive & Negative Feedback

- Total feedback: $f = f_0 + f_1 + f_2 + \dots$
- $f_0 = f_{\text{SB}}$: Stefan-Boltzmann
- Other feedbacks f_1, f_2, \dots :
 - Positive ($f_1, f_2, \dots > 0$): amplifies temperature change
 - Warmings \rightarrow hotter
 - Coolings \rightarrow colder
 - Negative ($f_1, f_2, \dots < 0$): diminishes temperature change
 - Warmings \rightarrow milder
 - Coolings \rightarrow milder

Stability of the Climate

- Most feedbacks we've discussed are positive:
 - Ice-albedo
 - Water vapor
 - Clouds (mostly)
- Why don't these positive feedbacks make the climate unstable?
 - (e.g., runaway greenhouse)
 - They are smaller than the negative Stefan-Boltzmann feedback
 - so the total feedback remains negative.
 - Positive feedbacks amplify warming:
 - More than we'd get with just Stefan-Boltzmann feedback,
 - But they are too small to destabilize the planet.
- Some scientists worry about a possible "tipping point":
 - Is there a temperature threshold where positive feedbacks become greater than Stefan-Boltzmann?
 - This would destabilize the climate.
 - Venus-style runaway greenhouse effect seems impossible.
 - But some uncontrolled warming is possible.

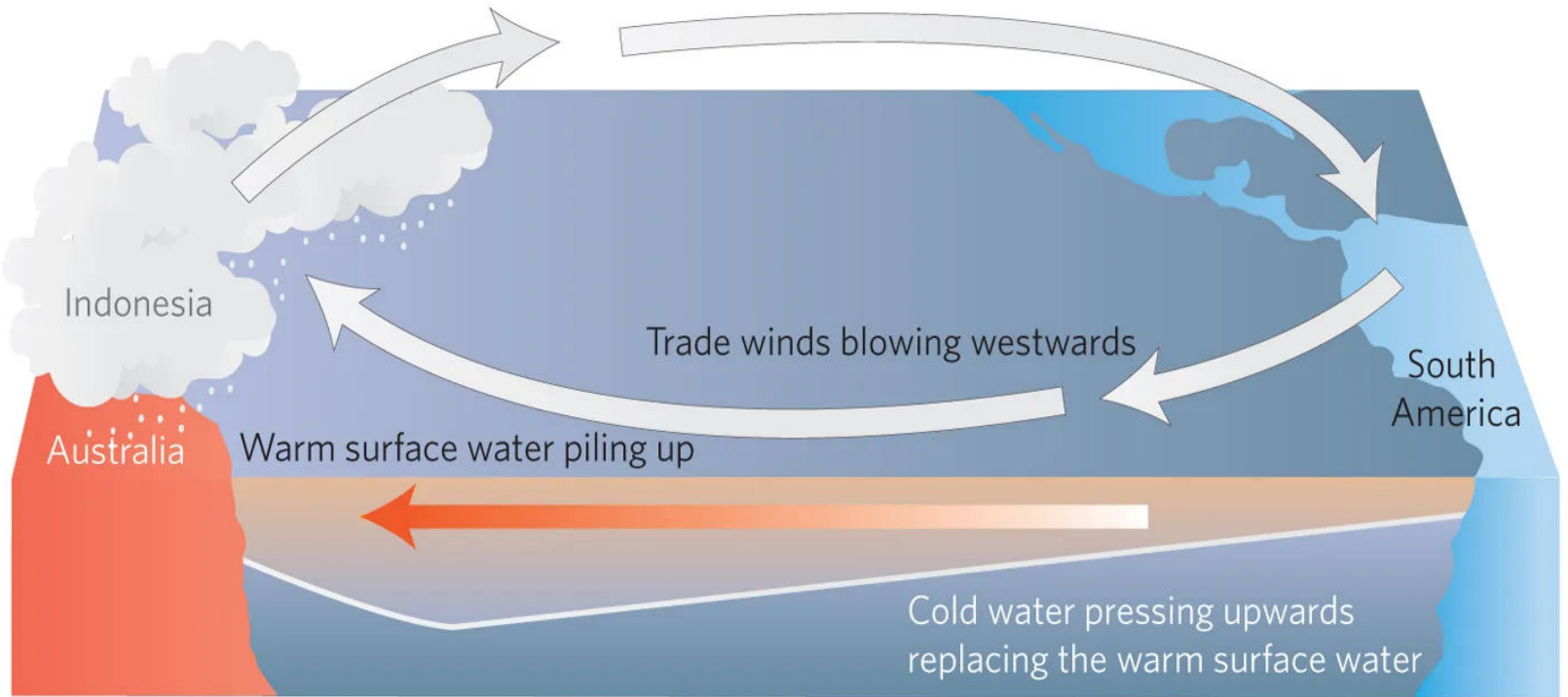
El Niño/Southern Oscillation



Normal Conditions

La Niña year

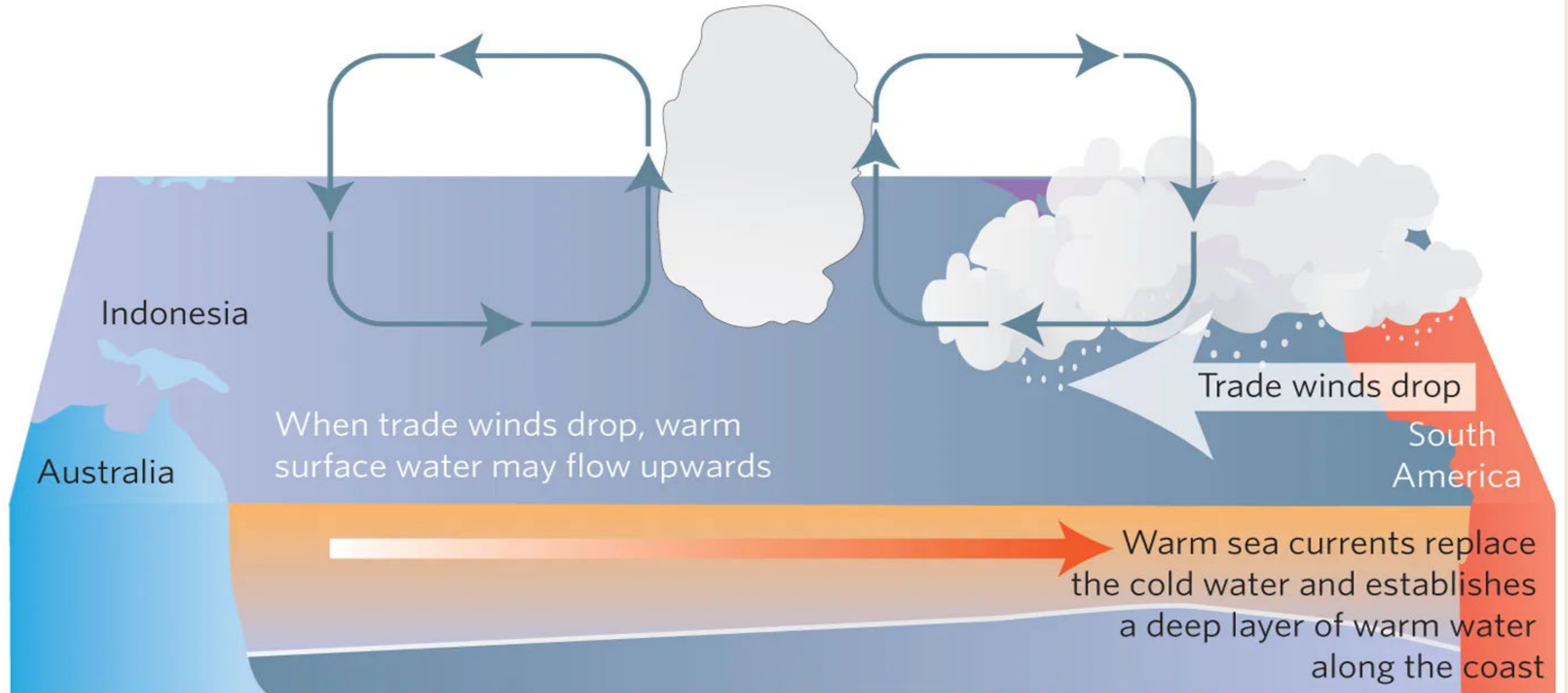
Walker circulation



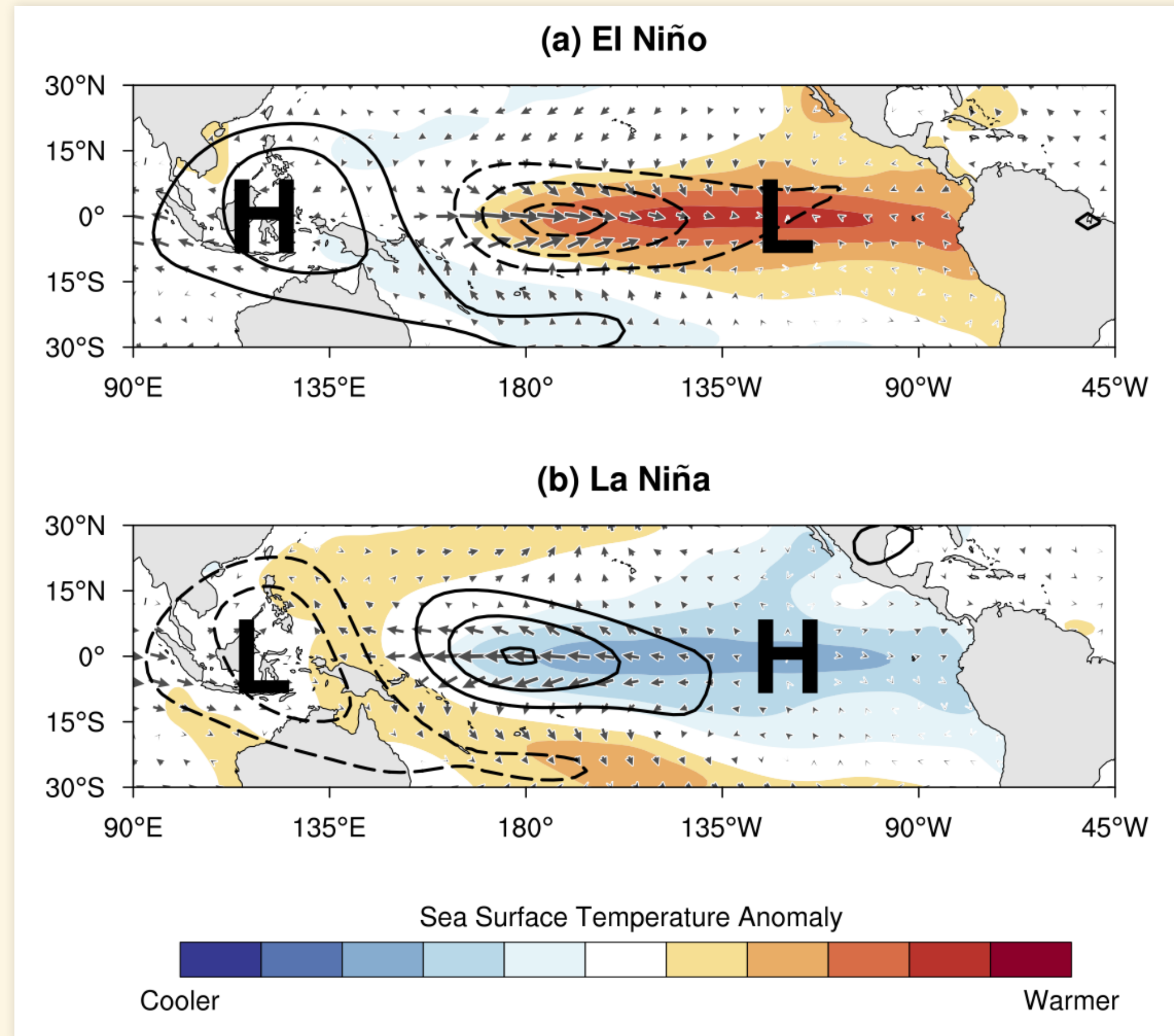
El Niño

El Niño year

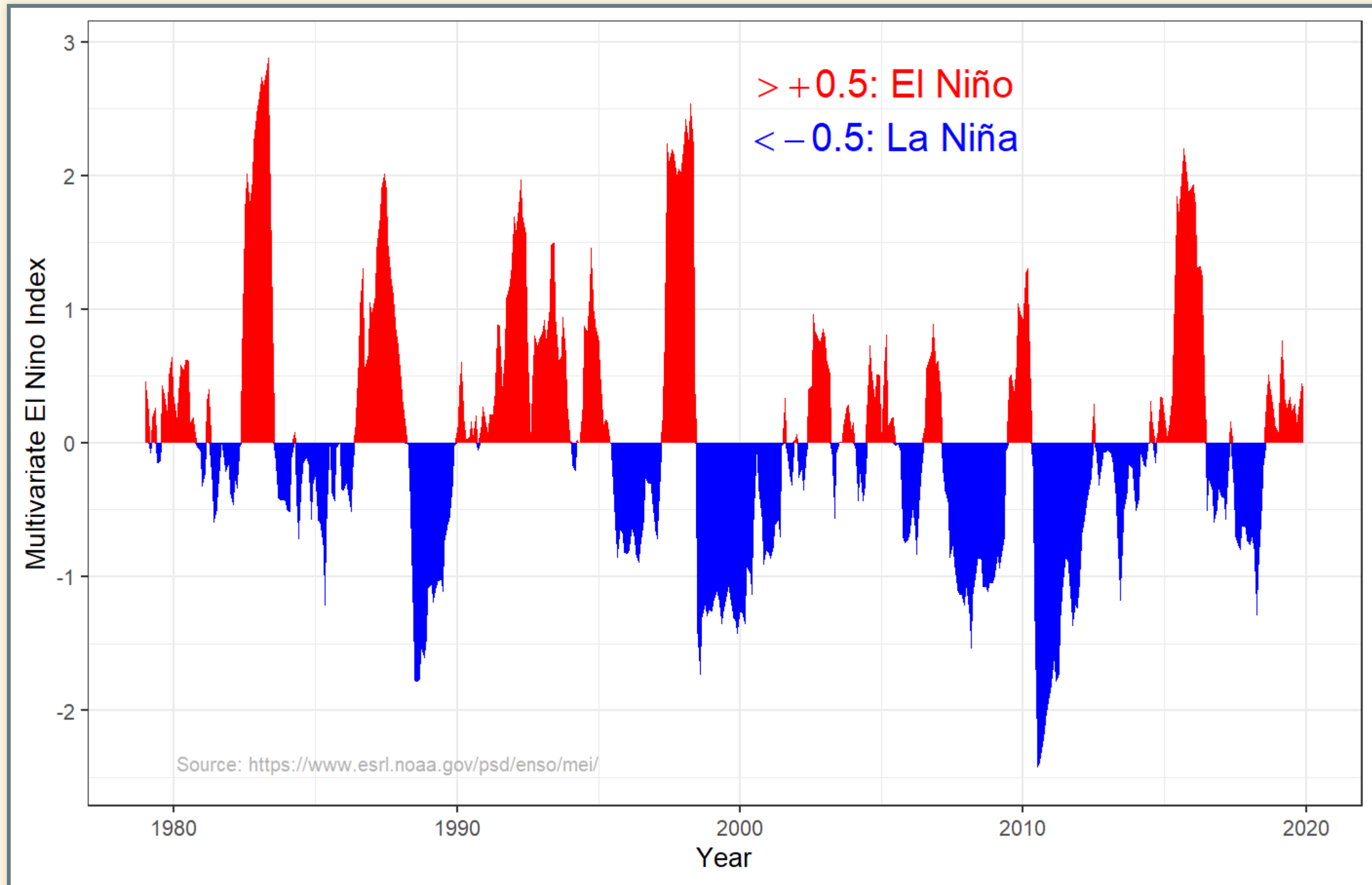
Increased convection



Schematic of ENSO Wind & Temperature



Multivariate El-Niño Index (MEI)



Climate Connection

- El Niño phase:
 - Hotter sea-surface
 - More evaporation
 - Bigger greenhouse effect
 - Higher global air temperatures
- La Niña phase:
 - Cooler sea-surface
 - Less water vapor
 - Smaller greenhouse effect
 - Cooler global air temperatures

Biosphere Feedbacks

Hydrological Cycle

- Transpiration in plants:
 - Roots take water from ground
 - Leaves emit water vapor
 - Evaporation cools the air
 - Can be an important source of water vapor

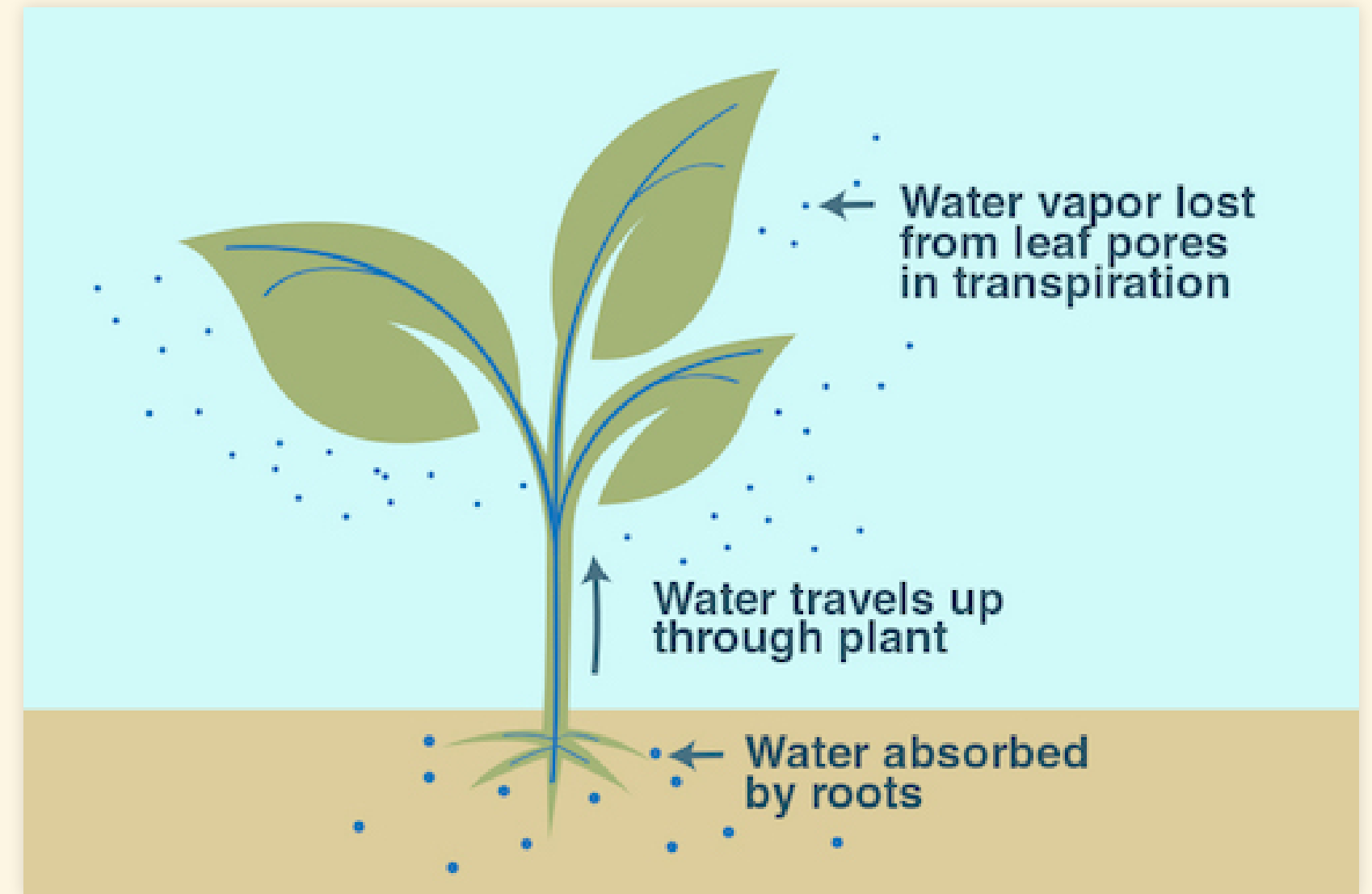


Image credit: NASA/JPL-Caltech <https://climatekids.nasa.gov/heat-islands/>

Transpiration and CO₂

- Transpiration occurs through “stomata” in leaves
- Tradeoff: stomata
 - Allow plant to get CO₂
 - Cause plant to lose water
- More CO₂ in atmosphere:
 - Fewer stomata
 - Less transpiration

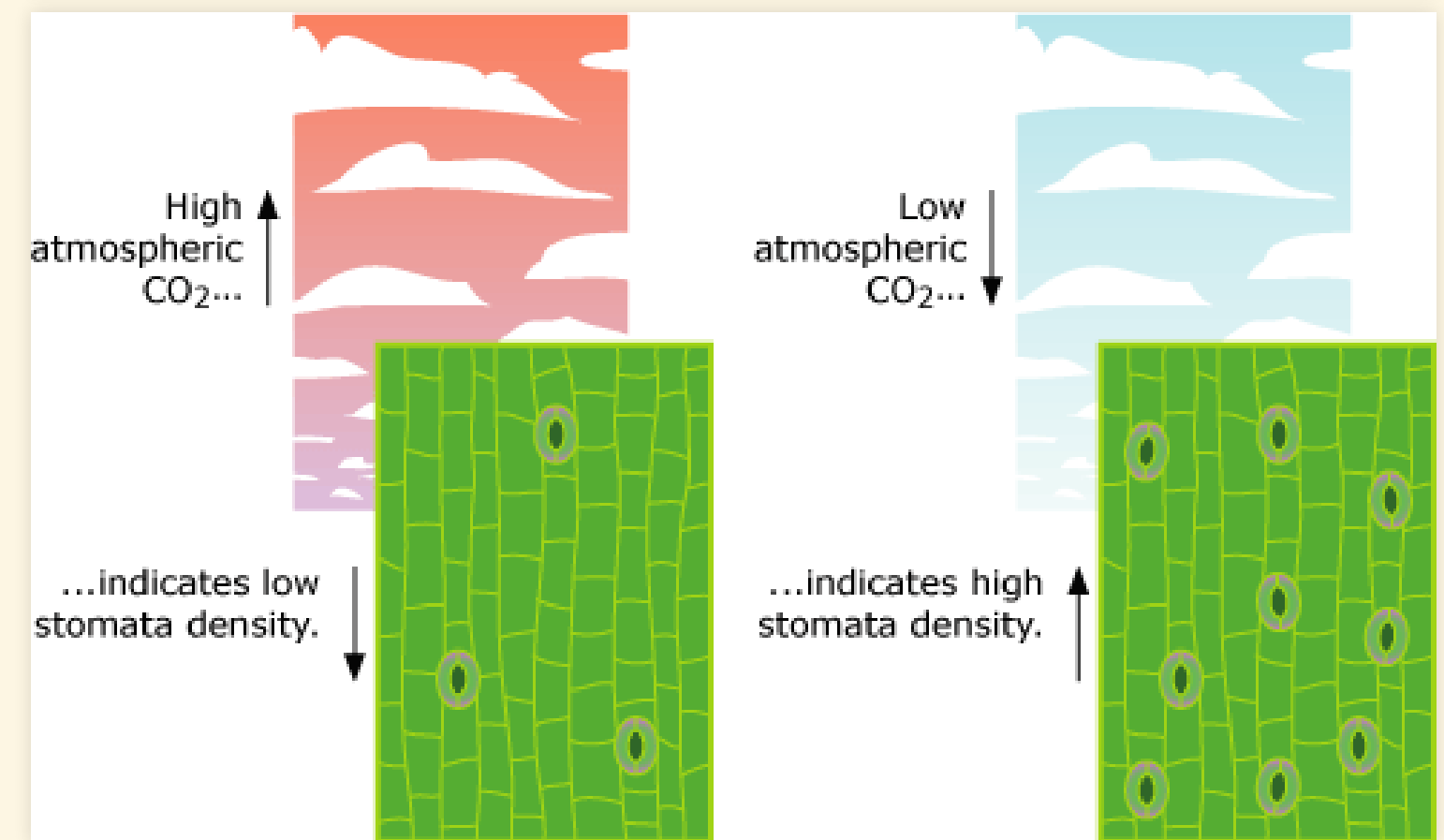
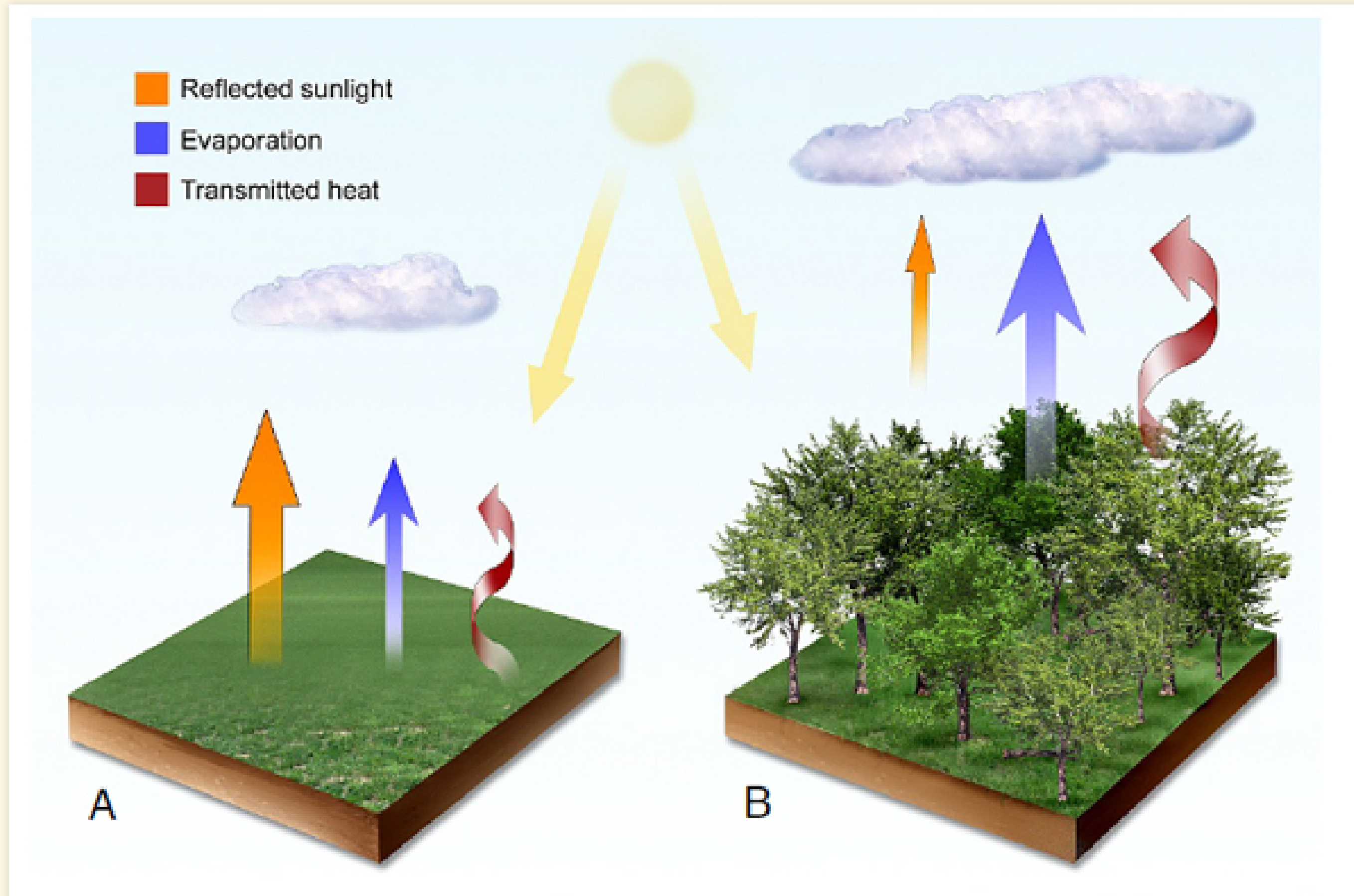


Image credit:

- Photo of stomata on duckweed: Micrographia <http://www.micrographia.com/specbiol/plan/planaq/plaq0100/lemna-01.htm>.
- Diagram of response to CO₂: University of California Museum of Paleontology's Understanding Evolution <http://evolution.berkeley.edu>.

Forests vs. Grasslands



Carbon Cycle Feedbacks

- Dead organic matter in ground (leaves, roots, etc.) stores carbon
- Warming temperatures accelerate decomposition
 - Bacterial/fungal metabolism
- Huge amounts of dead organic matter in arctic tundra & permafrost
 - Concerns about accelerated greenhouse gas emissions as ground thaws & warms

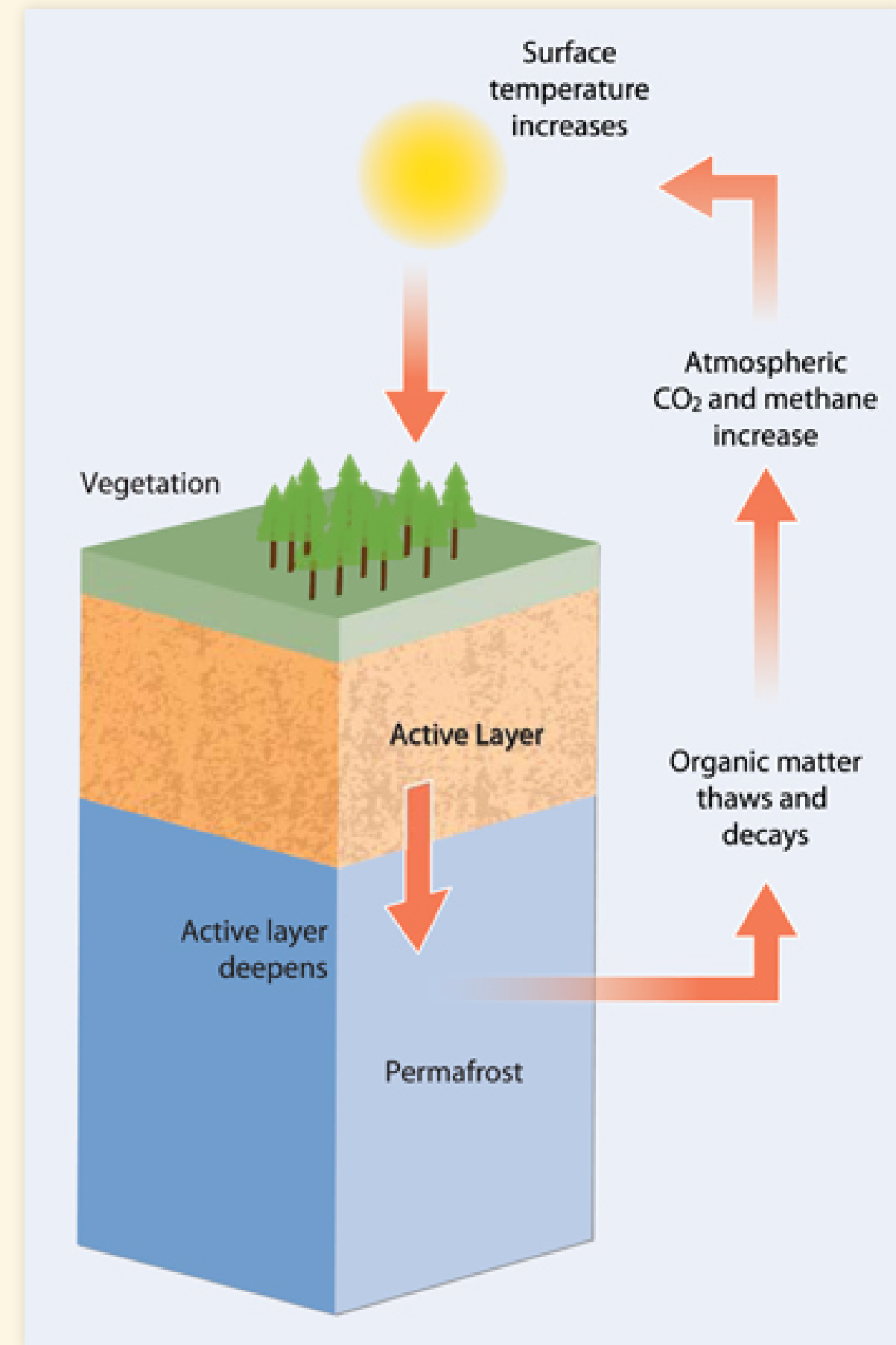


Image credit: K. Schaefer *et al.*, Environ. Res. Lett. 9, 085003 (2014). doi: [10.1088/1748-9326/9/8/085003](https://doi.org/10.1088/1748-9326/9/8/085003)